BYU Collegiate Wind Competition
Project Development Written Report

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Site Selection

It is proposed that the Louisiana wind farm be built throughout these three lease blocks: 46, 47, and 56. It will be composed of 30 GE Haliade-X 12 MW wind turbines for a total expected power output of 360 MW. This area avoids major shipping lanes and has only a few oil pipelines, which require any wind turbines to be at least 500 feet from each line. All oil pipelines, both active and inactive, are pictured in Figure 1.

The only federally protected traffic lane is the Louisiana Offshore Oil Port (LOOP) which is on the east side of the lease blocks and far from the selection. It is lightly outlined in red on the vessel traffic map in Figure 1. The other traffic lanes are mostly commercial traffic from the fishing business and oil rigs. Since these are important contributors to the state and federal economy, no turbines will be placed where they could disrupt major vessel traffic. The occasional vessel comes through the selected lease blocks and can reroute around the wind farm without difficulty. There are some areas that rarely have boats come through, but these locations are much farther from shore and would have greater material costs due to the increased water depth and cabling lengths. The three chosen lease blocks also avoid an important sand resource on the western border where sand and sediment are mined for crucial restoration of shorelines and marshlands [1].

Naval and military activity was also considered in the selection of the lease blocks, but no such activities are reported, nor are any warning zones recorded for the selected spaces. Because of the sensitivity and changing uses of offshore areas, resources are not published online determining which development locations might interfere with naval and military activity. In the development of the wind farm, it is critical to work closely with the US Department of Defense Siting Clearinghouse. The review process would include the analysis of how the proposed wind farm would interfere with radar, flight paths, and other security issues [2].

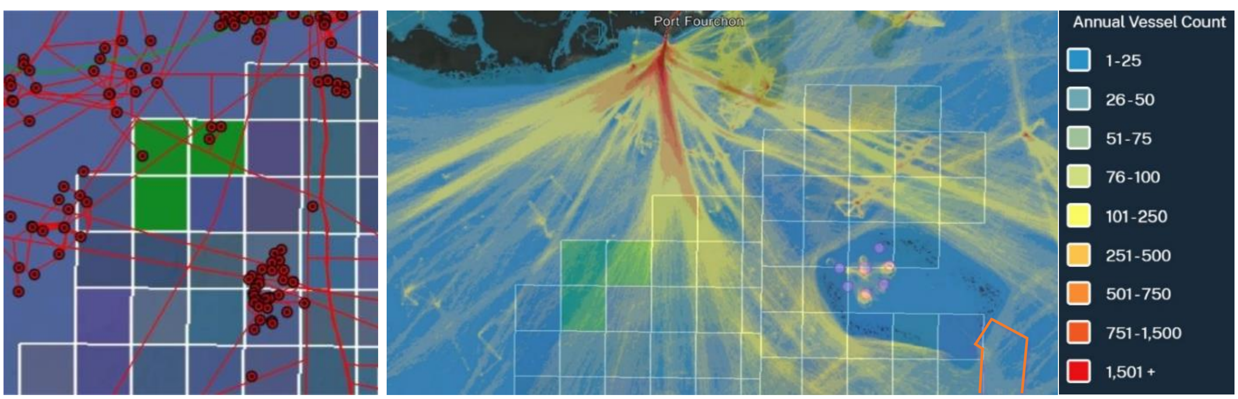

Figure 1: The selected lease blocks are highlighted in green. On the left are active and inactive oil rigs and pipelines. Vessel traffic, and its scale, are displayed on the right.

The mean wind speed at a height of 150 meters varies from 7.1 m/s to 7.2 m/s throughout all the available lease blocks, with the mean power density varying from 408-418 W/m^2 [3], shown in Figure 2. These densities have such a small variance between lease blocks that this was not a deciding factor in site selection.

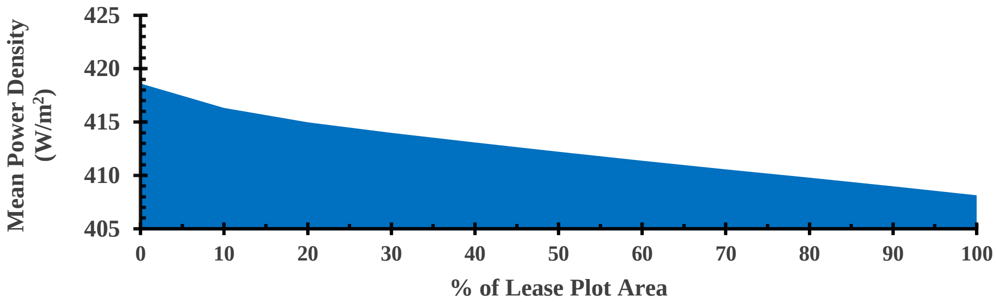

Figure 2: Mean wind power density throughout all possible lease blocks at 150 m, adapted from globalwindatlas.info/en.

Wind direction data was estimated by gathering data from Grand Isle, a city within 20 miles of the selected lease blocks, and correlates closely to the ocean data mentioned previously. Within the selected area, the predominate wind directions are southeast and northeast. The wind rose was generated by the Iowa Environmental Mesonet [4] and is shown in Figure 3. Though the data collection is 2.35 meters above sea level, the general wind direction is expected to be the same at the hub height. This wind direction was input into the layout optimization to minimize wake losses.

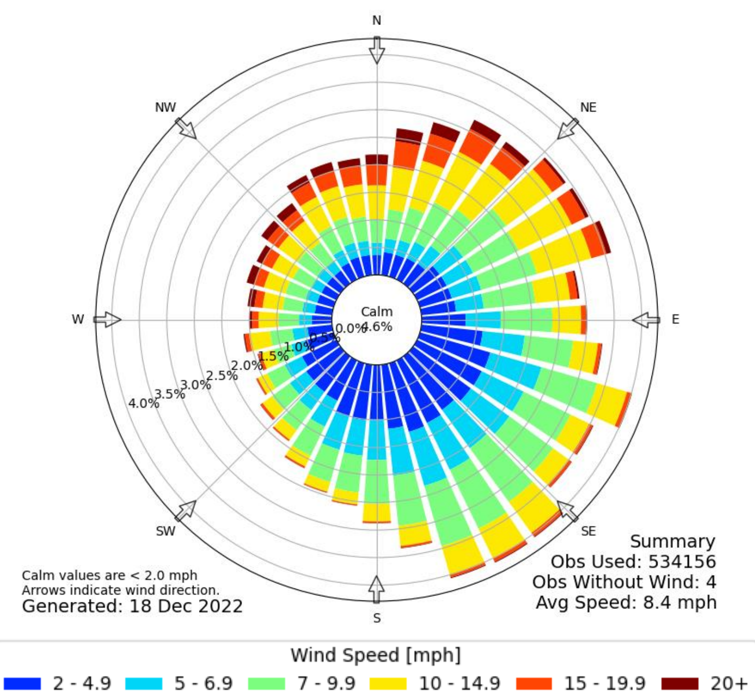

Figure 3: Wind rose for the nearby city of Grand Isle at a height of 2.35 meters above sea level.

The potential for hurricane impact is uniform across the lease blocks and hurricane considerations are discussed in the turbine selection. The average wave height in the Gulf of Mexico is approximately 4-6 feet above sea level, with the highest recorded wave reaching 22 meters high. The average wave height and sea surface roughness are uniform across all possible lease blocks [5].

Another important factor in site selection is bathymetry. The ocean depth varied throughout all lease blocks between about 14 and 50 meters. For cheaper and easier installation, a shallow depth is preferable. Any lease blocks shallower than the selected one were too heavily trafficked to be considered, and other lease blocks with a similar bathymetric profile were further from shore. Lease blocks deeper than 25 meters were not considered. A bathymetry map of the selected lease blocks is shown in Figure 4 and is labeled in units of meters. The depth varies from 19 to 22 meters. This figure also features the turbine and cabling layout for all 30 wind turbines. The turbines are all at least 500 feet from oil pipelines, represented as black dashed lines, and all cabling is routed to the offshore substation. This substation will then have cabling that connects to the Leeville substation.

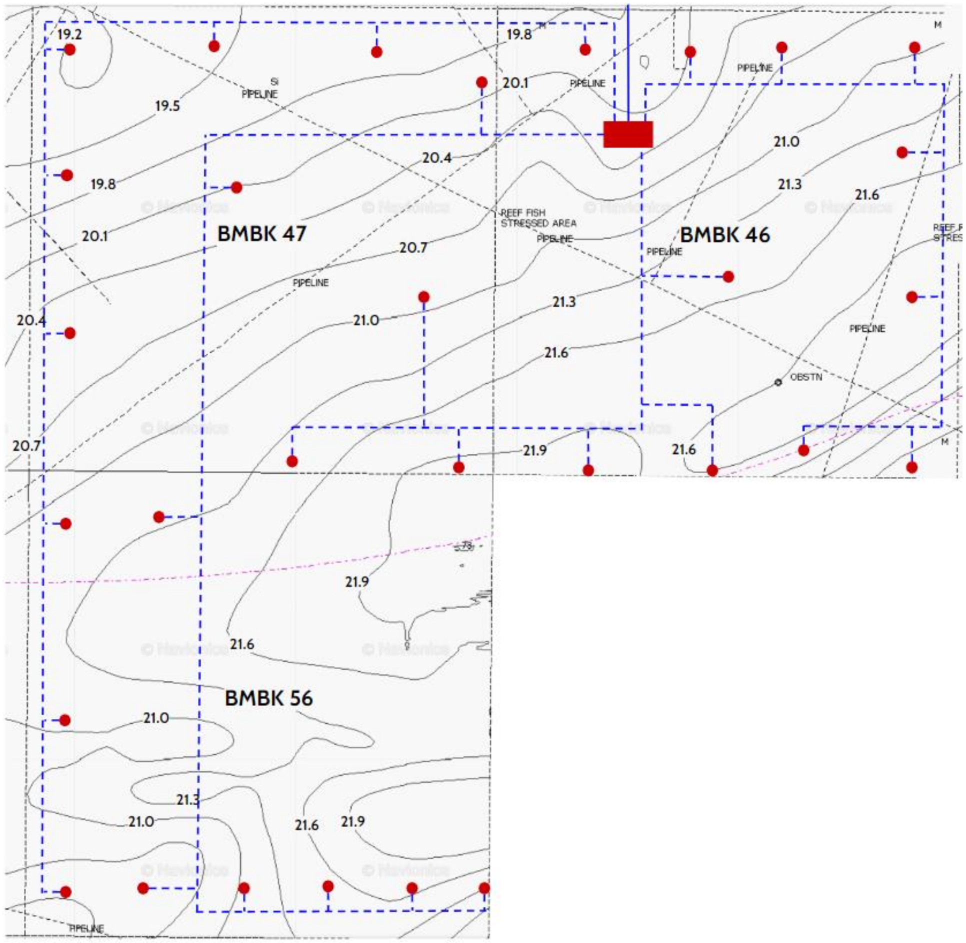

Figure 2: The turbine layout and its cabling are overlaid on a bathymetry map. The red dots represent wind turbines, the red box is the offshore substation, and the blue dashed lines are cables.

Environmental Considerations

Past and present oil drilling activity in the area need to be considered for placement of turbines in the lease area. Within the selected lease area, there were four oil platforms that, as of 2014, have all been removed, leaving behind oil pipelines. The turbines will need to be positioned in a way that accommodates these pipelines, as damage to either active or unused pipelines could cause residual oil spills. This risk can be mitigated by carefully installing the turbines' foundations and ensuring they are spaced appropriately from the pipelines.

The United States Code of Federal Regulations mandates that pipelines located near electrical transmission sources be protected from damage caused by fault currents or lightning strikes [6]. Because of this, it is legal to run cabling over both active and abandoned oil pipelines in the lease block, with the caveat that insulating devices be installed to protect the pipelines. When installing turbine cabling, or during normal operation, there is a risk of electrical currents being generated if the cables rub against the pipelines. To prevent this, the two systems can be electrically isolated using articulated padding. Furthermore, grout bags or other vertical/cradle supports can lift much of the cable weight off the pipe, reducing interaction between the cable and the pipeline. This approach is illustrated in Figure 5 below.

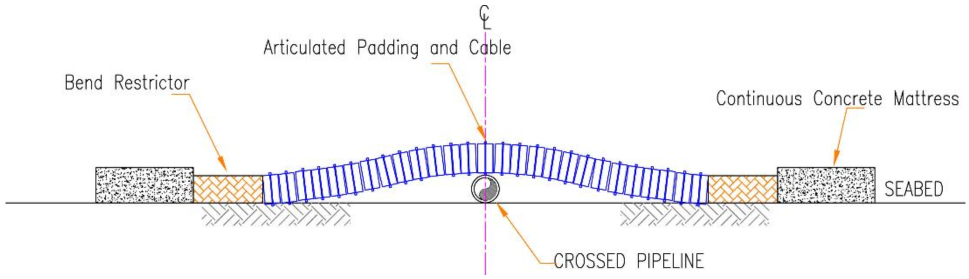

Figure 5: Demonstrates how cabling can be installed safely around oil pipelines [7].

The selection of lease plots for the wind farm project was carefully determined based on various factors, such as the location of surrounding reefs and protected areas. There are various species found in the water and air around the lease blocks and between the blocks and Port of Fourchon, making it necessary to implement environmental mitigation measures. The southernmost lease blocks were not considered in order to avoid damaging any coral, sponges, or reefs that are located in this area, which is designated as a critical habitat for endangered species and highly migratory fish and sharks.

According to information provided by US Fish and Wildlife [8], the only endangered animal present in the selected lease blocks is the manatee. Although this is not a critical habitat for them, the area they frequent will require mitigation tactics to ensure their safety. Research shows that noise pollution during construction is one of the most destructive disruptions to aquatic species [9]. The employment of the twisted jacket foundation instead of driving piles will greatly mitigate this risk factor since jackets require much less noise to install than piles do. Additional methods will include the containment of construction debris and the training of boat captains to recognize evidence of nearby manatees to avoid fatal collisions.

As mentioned, the selected plots are also in the migratory route of several avian species, so mitigation tactics such as painting and feathering the blades of the wind turbines are being considered to protect these birds. Fortunately, most of the 170 species of birds that migrate over Louisiana do so at elevations of 2000 to 5000 feet, well above the turbine height, self-mitigating much of the associated risk [10].

Overall, the careful selection of the lease plots and the implementation of mitigation measures will ensure that the wind farm project does not have a significant impact on the surrounding environment and its inhabitants.

Turbine Selection

This wind farm will feature GE Haliade-X 12 MW wind turbines. The entire lease block region is in an area with high hurricane frequency and intensity [11]. This turbine would be ideal for this location because it is designed to withstand extreme weather conditions and wind speeds since it is a Class IB turbine [12]. Class I turbines as defined by the IEC must be able to handle high wind speeds with an average of 10 m/s and gusts of up to 69.7 m/s [13]. It has a hub height of 150 m and a rotor diameter of 220 m, with other specifications summarized in Table 1 [14].

The Vestas V117-4.2 MW Typhoon turbine, which is also a Class I turbine, was seriously considered as well [15]. However, during an economic analysis comparing the small-scale turbine to the large-scale turbine, the cost to build many small turbines was significantly higher than the cost to build fewer large-scale turbines. The GE Haliade-X was ultimately cheaper for this scale of energy production, as indicated by a lower LCOE for the same wind farm capacity.

Table 1. Turbine specifications for the GE Haliade-X 12 MW turbine.

Rated Power	Rotor Diameter	Hub Height	Cut-in Speed	Power Density	Capacity Factor	Wind Class
12 MW	220 m	150 m	3.25 m/s	315.8 W/m^2	63%	IEC IB

Foundation Selection

After reviewing soil data, installation costs, environmental impacts, and weather conditions in the Gulf of Mexico, the Inward Battered Guide Structure (IBGS) foundation, also known as a twisted jacket foundation, has been selected [16]. In addition, the base piles used for the foundation will be suction buckets. Similar foundations are used in the oil and gas industries along the Gulf of Mexico [17]. The depth of water at the selected lease blocks reaches up to 22 meters, which is well within the safe operating range of the twisted jacket foundation. Floating foundations, monopiles, and other designs were not considered due to hurricane potential and the shallow water depth.

The twisted jacket suction bucket foundation provides numerous advantages, such as compatibility with the clay and medium-density sand that is found in the selected lease blocks [18]. Jacket foundations are also known to cause an artificial reef effect that will provide new habitats for local species. The suction bucket base is more economical to manufacture, requires less underwater installation work, and can be transported in greater quantities on smaller barges than other foundations. Additionally, twisted jackets have been reported to provide increased stability and hurricane survivability, which is a very desirable characteristic [19].

Hurricane Impacts

Understanding that Louisiana has a high likelihood of being in the path of hurricanes has led to the consideration of several mitigation factors for the wind farm. The twisted jacket foundation, suction bucket base, and typhoon-rated turbine will provide increased survivability, financial planning will factor in possible turbine loss [20], and battery powered yaw capabilities [21] will be added to each turbine to account for hurricanes.

Wind Farm Sizing

The optimal spacing between turbines is approximately 7 times the nominal turbine rotor diameter in the dominant wind directions, which originate from the southeast and northeast [22]. This is to prevent wind turbulence caused by one turbine from affecting the performance of another. With a rotor diameter of 220 meters, this spacing value will put approximately 1540 meters between each turbine [23]. In the nondominant wind directions, all turbines are spaced at least 3-5 diameters apart. These values, as well as estimated wake sizes from wind rose data, are accounted for in the wind farm layout in Figure 4 to optimize turbine efficiencies.

Due to the low prevalence of offshore windfarms in the United States, which have a total energy generation of 42 MW [24], this project provides an unprecedented opportunity to boost both the national energy output and the public opinion of offshore windfarms. With those two goals in mind, BYU will bid for three lease blocks. Accounting for natural and artificial obstacles, this would represent 30 turbines and an energy output capacity of 360 MW.

Optimization

Software was used to optimize the final layout shown in Figure 4. This optimization focused primarily on minimizing wake losses, since wakes severely decrease the power potential of the turbines caught inside them. For this reason, the turbines are spread along the borders of the lease blocks to minimize interference with the distances as specified above. With that baseline layout, financial outputs were produced via SAM to find ways to cut costs. Several wind turbines were adjusted to reduce cabling costs while still avoiding the wakes of other turbines. A few others had to be moved further from oil pipelines, but no other adjustments were made to the optimized layout.

Ocean Access

One of the major challenges that comes with an offshore windfarm is the transportation needed to both construct and service the turbines. Oceanic construction and maintenance will require at least five different kinds of vessels: survey vessels, lift boats, a service operation vessel (SOV), crew transfer vessels (CTV), and field development vessels (FDV) [25]. The smaller maintenance vehicles will operate out of Port Fourchon but larger operations, especially staging, will take place at the Port of New Orleans due to the magnitude of the cargo.

Before construction on the windfarm can begin, a geophysical survey of the ocean bed lying beneath the windfarm will need to be taken [26]. This survey will ensure that the seabed conditions match those expected from current GIS data. This should be done with an offshore survey vessel, hired by the windfarm. Fortunately, the large offshore oil industry present in the Gulf of Mexico makes finding a contractor fairly straightforward [27]. It should be noted that underwater survey is known to disturb and sometimes harm marine wildlife [28]. However, with no other reasonable options, a sonar survey will have to be conducted.

The construction of the windfarm will begin with the lift boat and will likely require a specialized Wind Turbine Installation Vessel (WTIV) [29]. A WTIV is a large ship with a length greater than 150m. Additional site preparations will be made by one or more Field Development Vessels (FDVs). These are large ships capable of laying down the necessary undersea cabling to interconnect the turbines as well as connect the wind farm to a land-based substation [29]. These vessels will need to operate out of a large-scale port capable of servicing large ships, such as the Port of New Orleans.

Maintenance will be performed by two different types of ships working in tandem. First, a large SOV will be permanently stationed inside the wind farm. This ship is meant to carry out heavy maintenance of turbines, and includes equipment such as dynamic positioning, cranes capable of moving large replacement parts, and gangways to transfer work crews to a turbine. Transportation of work crews from shore to the SOV would be performed by much smaller CTVs. The small boats will operate out of Port Fourchon. This port provides quicker access to the windfarm due to its relative location. Multiple CTVs will need to be owned by the wind farm [25].

Both the WTIV and the FDVs are large and expensive craft. Because they are only used for construction, they will likely be rented by the wind farm as the turbines are constructed. These ships, as well as the SOVs, will have to be compliant with the Merchant Marine Act of 1920, better known as the Jones Act. This federal law mandates that ships carrying people or goods between two harbors in the United States be registered in the United States. The first Jones Act compliant WTIV is slated to be available for use by 2025 from Dominion Energy [30].

Cabling and Transmission

For offshore wind farms far from shore, DC transmission is most effective to eliminate loss, but because the farm is within 50 miles of a substation, it will use high voltage alternating current (HVAC) transmission [31]. High voltage allows for low current with the same power transmission. High current leads to power loss and requires larger cables, so low current is ideal. The disadvantage to using AC current is that cable charging current occurs. To help alleviate cable charging through cabling between the wind turbines and the shore, an offshore substation with reactive compensation will be built within the wind farm. This substation will act as a hub, collecting the power created by the turbines and then transmitting it at 245-290 kV to the onshore substation [32]. Potential energy loss due to electrical systems is shown in Figure 6.

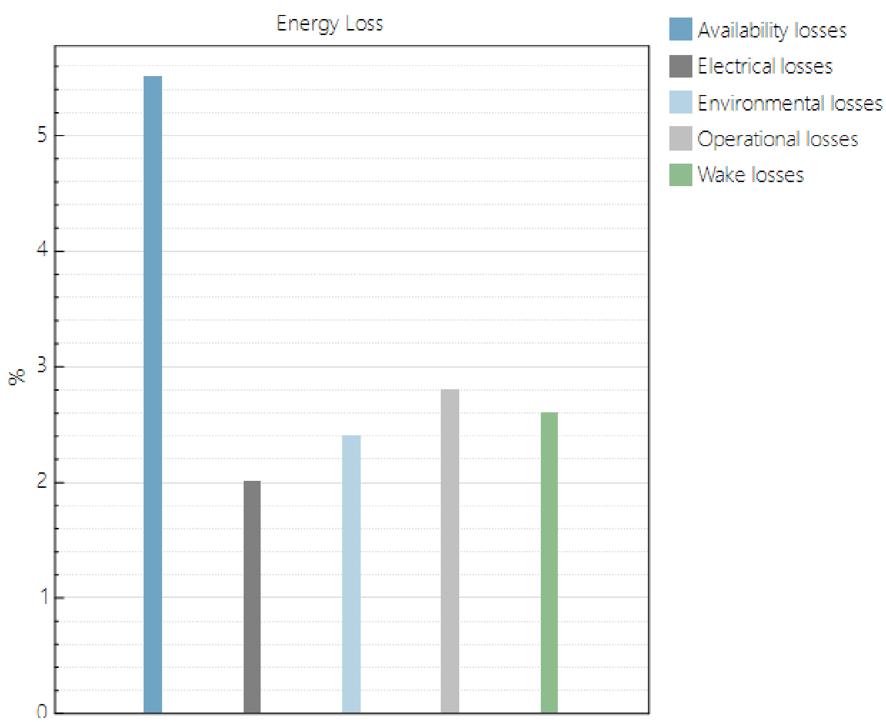

Figure 6: Graph shows how much of the energy produced by the turbine is expected to be lost due to various factors, including electrical.

As seen in Figure 4, the cabling has been arranged in a radial feeder collection pattern to connect the wind turbines to the offshore substation. This pattern minimizes cabling costs and works well for single wind farms close to shore. [also 27, NOWEGIS]

An ideal grid interconnection site would be close to the nearby Port of Fourchon. This would minimize the amount of cabling needed to transfer the electricity to land and lies close to the wind farm's principal base for maintenance operations as previously mentioned. The onshore substation to which the wind farm will connect is the local utility substation in Leeville, a mere 28 kilometers from the offshore substation [33]. See Figure 7.

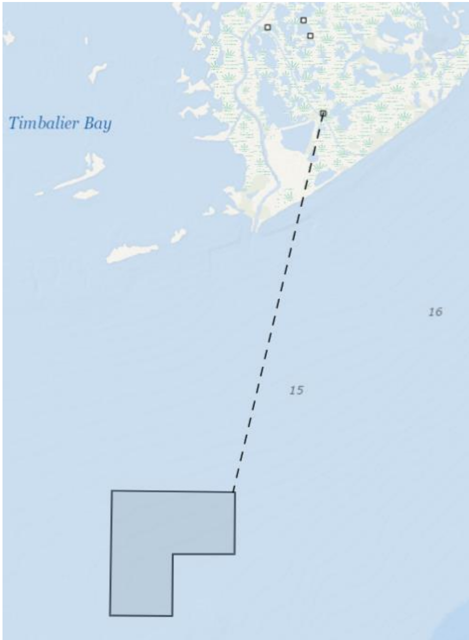

Figure 7: BOEM Ocean Reports image of nearby substations, with the nearest being 28.26 km from the selected lease plots [19].

Social Considerations

Public opinion and social impact can determine the success of any infrastructure project. A recent 2022 poll by the Greater New Orleans Housing Alliance showed that only 44% of Louisiana voters had a favorable view of renewable energy [34]. This is due in large part to the strong influence of oil and gas companies in the state. With this public opinion polling data in mind, the site has been selected to minimize social and economic impact on Louisiana residents. The selected site avoids not only federally protected shipping lanes but also areas of major vessel traffic and fishing activity.

The area selected is also at least 30 miles from the nearest residential area which is farther than the recommended 15 miles for aesthetic preference [35]. The selected site appears to be clear of any tribal lands but input from the closest tribes, the Houma and Chitimacha, should be received and considered [36]. A public relations campaign and town hall meetings will need to be held with residents to explain the impact of the project, answers residents' questions, and ensure that the project has the support of the public and that any negative social impact is minimized.

Financial Analysis

Capital Expenditures

The main capital costs were found using NREL's System Advisory Model (SAM). SAM factors in an extensive list of inputs to provide an estimate of the overall cost. Many of the inputs were existing values like those claimed by GE for their turbine. Many other values were estimated in the calculations like the turbine layout and locations. Finally, many values were estimated based on previous projects such as wind losses and operating costs. Everywhere possible, offshore financial estimates were used in place of onshore wind financial estimates, as the two vary greatly. There is uncertainty in the estimates given for capital cost, however they align well with cost estimates from energy companies.

The estimated cost of the turbines is pulled from the Vestas Annual Report, which states that the average selling price of one of their wind turbines is $944,000 per MW capacity of the turbine [37]. A 12 MW turbine is thus expected to cost $11.3 million. The cost of the 30 turbines for the wind farm is $340 million. As competitors, General Electric is assumed to have a similar average selling price to Vestas.

The balance of system costs was also critical in determining the capital expenditures. The balance of system costs evaluates the cost of installing the wind turbines as well as the foundation, cabling, and other important infrastructure. These costs often are the most expensive portion of wind farm development, and as such must be treated with great care. The balance of system costs were estimated using SAM’s built-in Offshore Balance of System Cost Model. This model receives inputs regarding the number of turbines, location of wind farm, foundation type, installation strategy, and transportation logistics. As many inputs as available and reasonable were considered to ensure an accurate representation of what the cost would be. The balance of system cost is $1.28 billion.

Financing Plan

The project will be financed from a combination of debt, tax equity, and funding from a private entity. The combination of these three will provide sufficient funding for the $1.62 billion capital cost. The project will be financed using a partnership flip structure. The partnership flip means the owner of the project will receive most of the funding from a separate entity who will receive large tax benefits. After a given period of time, the ownership of the wind farm will flip, so that the private entity will own a significantly smaller portion of the wind farm. The partnership flip will be set up in a 98/2 ownership split before the flip, and a 10/90 split after the flip. This means that the private entity that helps fund the project will own 98 percent of the project and receive 98 percent of the tax benefits before the flip, and own 10 percent of the project and receive 10 percent of the tax benefits after the flip. The project owner will own the remaining portions of the wind farm before and after the flip. The financial data from SAM shows that the ideal amount of time before the partnership flip would be just one year after energy production begins. One year will optimize the overall cost of the project while still providing a large benefit to the investors. This means that the private entity would be benefitting from the large ITC as well as the first-year depreciation of the wind farm. For the remainder of the project the private entity would own 10 percent of the project and continue receiving 10 percent of the tax benefits.

Power Purchase Agreement

In order to pay back the debt and pay for the funding received from the private entity the project will use a power purchase agreement. This means that the wind farm will sell electricity to power companies in Louisiana at a set amount to pay back all the funding received for the capital cost of the project. The wind farm will use a fixed PPA price of $0.11 per kWh with an annual escalation rate of 1%. The calculations in SAM show that the best PPA price will be $0.11 per kWh. A PPA price of $0.11 per kWh will cover all the capital costs as well as provide a return on the investment for the private entity in the partnership flip. The partner would receive an estimated $81.2 million return on investment throughout the lifetime of the project, making it an attractive investment.

Market Opportunities and Constraints

Levelized cost of electricity (LCOE) gives an overall estimate to the cost of electricity when all costs are factored in. The calculations from SAM show that the energy obtained from the wind farms will be sold to companies that distribute energy in Louisiana. Current state averages estimate the cost of electricity in Louisiana to be 12 cents per kWh [38]. A sales tax of 5% was assumed for all calculations. in the project. A slightly higher value than Louisiana's sales tax was used to be conservative and factor in any project work done in other states. The PPA calculations show that energy from the wind farm would cost a competitive 11 cents per kWh. The PPA price, however, is just the cost charged to the consumers of the electricity. The LCOE will be a slightly lower value than the PPA value because LCOE does not factor in the profits for the investors (which is necessary to receive financing for the project). The nominal LCOE for the entire project, which is based on capital costs and operating and maintenance costs, is estimated by SAM to be $0.849 per kWh. These values, and others, are shown in Figure 8.

Metric	Value
Annual AC energy in Year 1	1,198,069,888 kWh
Capacity	360,000 kW
Capacity factor in Year 1	38.0%
PPA price in Year 1	11.00 ¢/kWh
PPA price escalation	1.00 %/year
LPPA Levelized PPA price nominal	12.24 ¢/kWh
LPPA Levelized PPA price real	9.72 ¢/kWh
LCOE Levelized cost of energy nominal	8.49 ¢/kWh
LCOE Levelized cost of energy real	6.74 ¢/kWh
Investor IRR Internal rate of return	17.97 %
Flip year	1
Investor IRR at end of project	22.66 %
Investor NPV over project life	$81,164,616
Developer NPV over project life	$395,881,088
Net capital cost	$1,756,635,520
Equity	$517,544,832
Debt	$1,239,090,688
Debt percent	70.54%

Figure 8: Data from SAM showing a summary of the finances.

Incentives and Depreciation

The project will opt for the investment tax credit (ITC) for the upfront benefits. The ITC allows for a 30% tax credit on the dollar amount of the investment for costs of the project [39]. The project will opt for the ITC over the production tax credit (PTC) because it will provide a large upfront credit rather than a sustained credit over a long period of time. The PTC would offer a set amount of tax credit per kWh produced by the wind farm. However, an upfront strategy would be preferred. This upfront strategy will make the project a much more attractive investment for the PPA. While the PTC could potentially save more money in the long run it has the potential of making the project appear risky or not beneficial enough for investors. Thus, to make the project more able to secure funding, the ITC will be favorable over the PTC. The construction on the wind farm will begin by the end of 2023 so it can be eligible for the ITC.

An additional 10% ITC is available if the turbine meets specific requirements. Requirements include that 100 percent of the steel be manufactured in the US, and 40 percent of all other components be manufactured in the US [40]. While this would help decrease the cost significantly, there is no way to be eligible for this tax credit under current circumstances. GE does not manufacture any offshore turbines in the US and will likely not for any time in the near future.

The project will assume a 5-year 100% MACRS depreciation. A 5-year 100% MACRS defines the project to depreciate completely in value over the course of the first five years [41]. This will be used to apply a higher amount of tax benefits to the front end of the project. A project with front-end benefits will make the project more attractive to potential investors in the PPA.

Operational and Maintenance Expenditures

The annual operational and maintenance (O&M) costs were calculated using SAM. The expected O&M costs are $15,480,000 annually. These costs are calculated by SAM on a per-kW basis, and is dependent on the number of turbines, the location, turbine manufacture warranty specifications, and other factors. O&M costs are understudied and as such difficult to draw specific conclusions from. The exact details of O&M costs are not available until a windfarm has completed its lifetime, which can be upwards of 20 years. Few wind farms which have been operating for 20 years, and those which have been operating this long utilize outdated turbines which cannot be used to model the O&M costs of current turbines. Due to the complicated nature of O&M costs, the SAM default O&M estimates were utilized [42].

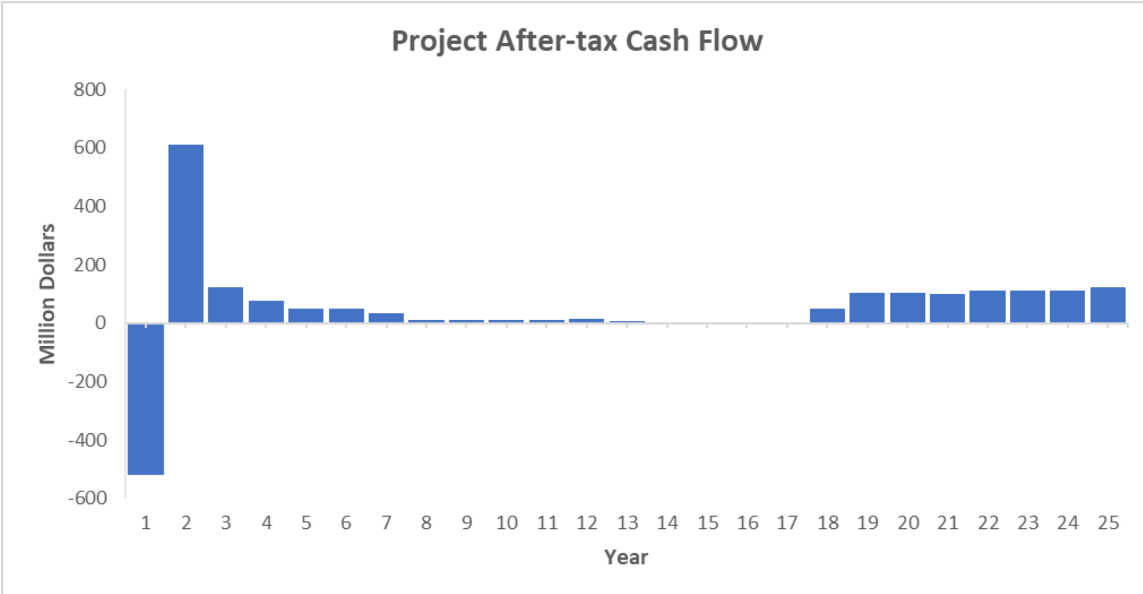

Figure 9: Data from SAM showing the 25-year after-tax cash flow.

Bid Amount

The owner of the project will bid $37,065,800 for the 3 lease blocks. This was determined by comparing the cost per acre for previous offshore wind farms currently operating in the United States for more than $2500 per acre [43]. Considering the that the offshore wind sector in the United States is relatively new, though gaining traction and interest quickly, a bid of $2000 per acre was deemed sufficient to win the auction without significantly overpaying.

The project financial plan successfully produces a significant value for investors. The NPV for investors over the life of the project exceeds $80,000,000 which allows for the proposed bid to be made and still be a financially viable plan.

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